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A Flexible Package and Interconnects for Microfluidic Systems

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A flexible package and interconnects for microfluidic systems

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ABSTRACT

A slide-together compression package and microfluidic interconnects for microfabricated devices requiring fluidic and electrical connections is presented. The package assembles without tools, is reusable, and requires no epoxy, wirebonds, or solder, making chip replacement fast and easy. The microfluidic interconnects use standard HPLC PEEK tubing, with the tip machined to accept either an o-ring or custom molded ring which serves the dual function of forming the seal and providing mechanical retention strength. One design uses a screw to compress the o-ring, while others are simply plugged into a cartridge retained in the package. The connectors are helium leak-tight, can withstand hundreds of psi, are easy to connect and disconnect, are low dead volume, have a small footprint, and are adaptable to a broad range of microfabricated devices.

Keywords: Microfluidics, interconnects, packaging, MEMS

1. INTRODUCTION

Miniature fluidic systems incorporating micromachined devices are making possible the next generation of analytical instrumentation for medical diagnostics, drug discovery, chemical synthesis, and counter biological warfare efforts. Bulk and surface silicon micromachining, glass etching and ultrasonic drilling, electroplating, and polymer molding, combined with techniques for bonding various substrates together have enabled the fabrication of micron to millimeter scale flow channels, separators, sensors, pumps, valves, reaction chambers, and mixers for handling chemical and biological fluids. These new devices and systems are more than just miniaturized versions of larger components manufactured using traditional methods -- they exploit unique physical phenomena and advantageous scaling effects which occur at the micro-scale. While a great deal of work has focused on the fabrication and function of microfluidic devices, very little has been published concerning the packaging of microfluidic systems. Critical and challenging packaging issues include microfluidic interconnects (device to device and interfacing macro components to micro devices), providing electrical connections while maintaining isolation between electronics and fluids, and mounting and encasing devices such that they are easy to assemble while providing the appropriate interface to other devices or the external environment. In some applications, the microfabricated part is disposable, or the fluidic device must be easily replaceable to facilitate instrument servicing. For effective packaging, design and microfabrication of the fluidic chip must be considered carefully.

A common approach for making microfluidic interconnections to bulk micromachined silicon devices is to insert tubing into an anisotropically-etched fluidic port in the face or on the edge of the device and using epoxy to form a seal. A grommet or barbed fitting sometimes is glued onto the device to provide mechanical strain relief. Some drawbacks of such an approach include potential for epoxy to clog channels, epoxy curing time, irreversibility of the connection, and the fact that epoxy will contact the working fluid. Deep reactive ion etching has been used to couple standard capillary tubing with silicon-based microfluidic devices.[1] Dead volume was minimized in these couplers by carefully matching the silicon etch dimensions to the capillary size and by precisely cleaving the capillary tip, although epoxy was required to secure the capillary in place, which led to channel clogging. Alternatively, a sleeve etch was used to isolate the epoxy from the microchannels, but this increased the dead volume associated with the connection. In a third design, the same group used an injection molded plastic connector which was heat-staked through a silicon/glass device. This coupler, when used with a silicone gasket, did not leak when pressurized up to 60 psi with liquids, and withstood pull-out forces up to 2 N. In this paper, we present a compact, easy to assemble, reusable microfluidic packaging scheme which combines a new interconnect with a slide-together compression package.

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2. SLIDE-TOGETHER COMPRESSION PACKAGE

An analogy exists between Microelectromechanical systems (MEMS) and integrated circuits: ideally, MEMS would consist of discrete functional components which could be integrated into a broad range of systems using standard processes and batch fabrication. Integrated circuits, however, are able to take advantage of universal packaging schemes because in all cases the objective is to make electrical connections while providing permanent protection from the environment. Most MEMS, on the other hand, must interface with their environments, for example by allowing fluids to enter and exit, and the requirements vary from system to system. For this reason, there is a need for microfluidic packaging solutions which are general in concept yet flexible enough to allow for variations in system requirements. In a DARPA-sponsored collaborative effort with the University of Texas M.D. Anderson Cancer Center, LLNL has developed a generalized microfabrication and packaging scheme and applied it to a microfluidic separation and detection system aimed at differential blood cell counting and air-borne pathogen monitoring. Particle separation and identification are broadly sought-after functions within the scope of microfluidic systems, both for sample pre-treatment and analysis. The method of separation involves the use of dielectrophoresis (DEP) combined with pressure-driven flow as a means for achieving field-flow-fractionation,[2] and particles are identified using AC impedance sensing.

Packaging and fabrication of the fluidic chips were considered carefully from the beginning of the design process to ensure that critical requirements were met, including ease of chip replacement (no epoxy, solder, or wire bonds), visibility of the microchannels through a microscope (this requirement necessitates both a transparent device and a low profile cover), opposed electrodes in contact with the fluid and sealed within the microchannels, compact size, short lead lengths to critical electrical components, and high pressure (up to 1000 psi) inputs. The fluidic chips were designed with electrical and fluidic contacts on the same side to facilitate surface mounting onto a PC board and to allow for visualization of the flow. To fabricate the chips, two borosilicate glass substrates were fusion bonded together, as depicted in Fig. 1.[3] Before bonding, holes were ultrasonically

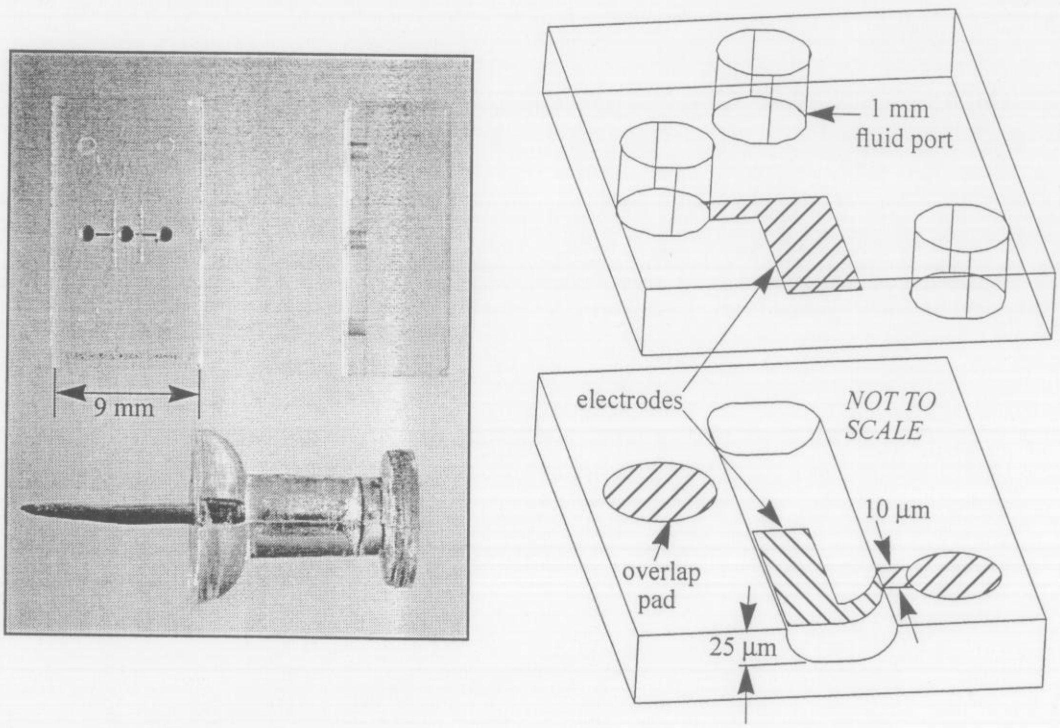


Figure 1. Microfabricated particle impedance sensor (top and side views) for detecting and identifying cells and particles. This device has 20 μm deep channels with opposed electrodes. The illustration shows how the devices are fabriucated. Two glass substrates--one drilled to make fluidic and electrical contacts, and one etched for flow channels--are bonded together.

drilled in one plate for contacting the electrodes and for providing fluid ports, and channels were etched into the other plate. Both the separator and sensor chips were fabricated using the same process, which ultimately will allow for a single horizontally integrated chip providing both the separation and identification functions. A photograph showing the top and side views of the impedance sensor chip also appears in Fig. 1.

Figure 2 shows top, bottom, and disassembled views of the package for the impedance sensor. While discussed here in the context of a specific application, the packaging approach is easily adaptable to other microfluidic systems, and has been used with other devices including the DEP separator. The impedance sensor chip mounts on the back side of the PC board to isolate the fluidics from the electronics. This configuration allows for a very short lead length--essentially the thickness of the PC board--

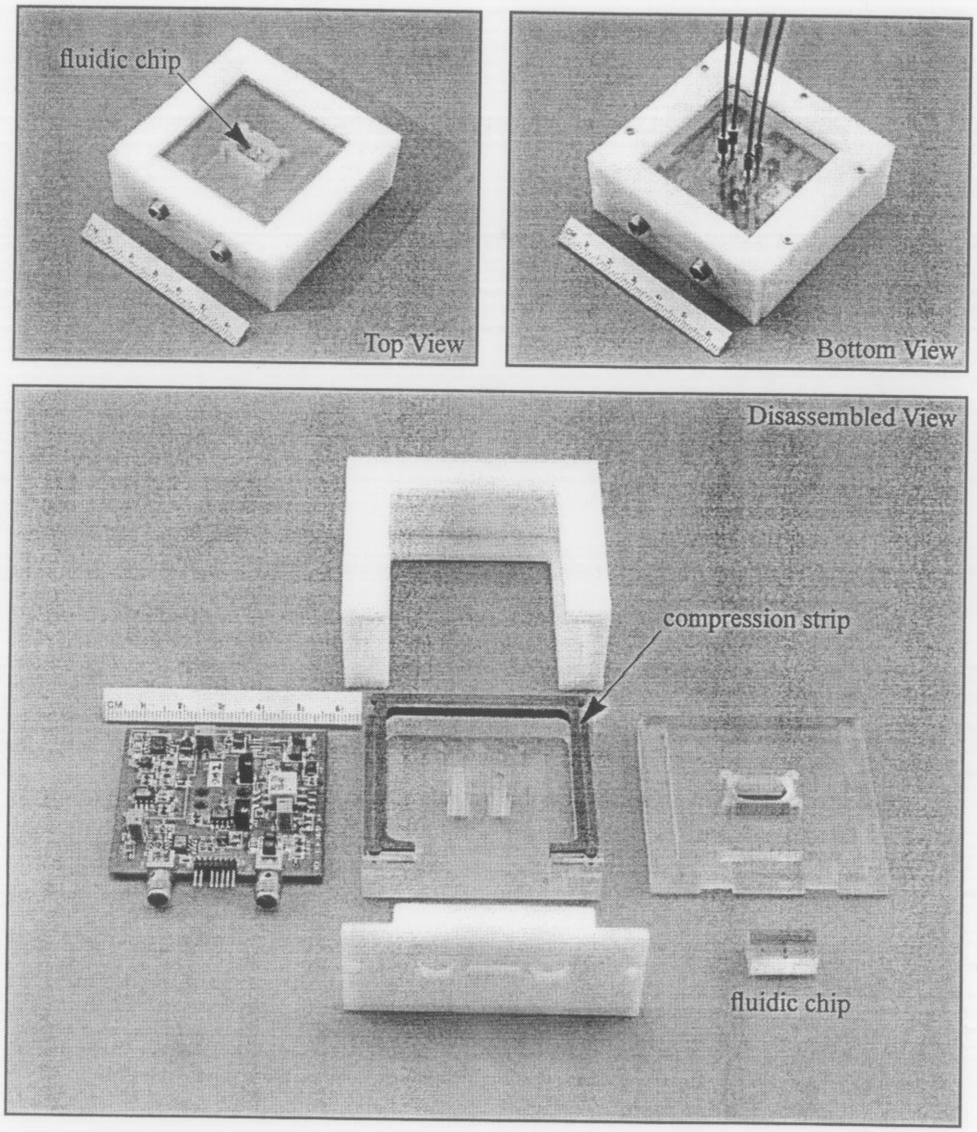


Figure 2. Top, bottom, and disassembled views of slide-together compression-package for the AC impedance sensor. No tools are required for assembly, and the fluidic chip is easily replaced, with the use of epoxy, wire bonds, or solder. The fluidic chip is mounted on the back side of the PC board to isolate it from the electronics. Bottom view shows the fluidic connections to the input and output ports.

connecting one of the sensor electrodes to a critical electronic component mounted on the other side of the board directly opposite the fluidic chip. An overlapping metal pad is patterned on the bottom glass substrate to make contact with electrodes patterned on the top substrate (see Fig. 1). Contact to the electrodes is made using 1 mm diameter compressible conductive elastomer pillars, bore cut from silver-filled silicone sheet (Chromerics Inc.), which are placed inside the drilled holes, as illustrated in Fig. 3. This approach eliminates the need for epoxy, solder, or wirebonds, making the devices easily replaceable.The white package frame and clear plastic plates shown in Fig. 2 slide together, compressing the silicone rubber strip and pressing the chip against the PC board. Other microfluidic devices, including the DEP separator and MHD pump, were packaged with the same frame after modification of the plastic plates to accept different chip sizes and connector layouts. The fluid connectors, described in the next section, insert from the bottom of the package (see Fig. 2, bottom view) and pass through drilled holes in the PC board where they interface with the fluidic chip. The entire system is assembled by hand without any tools required other than tweezers for inserting the polymer electrical contacts.

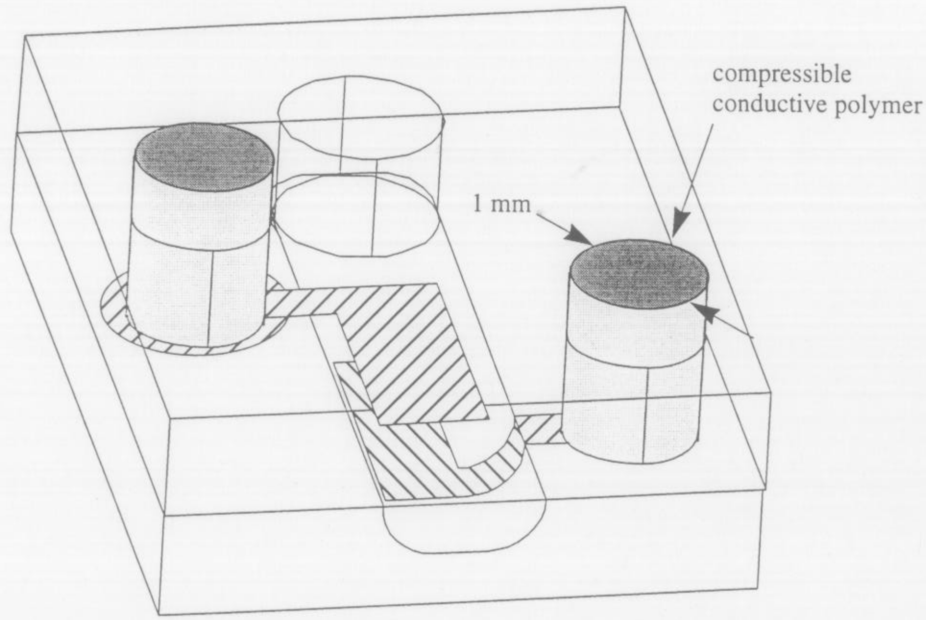
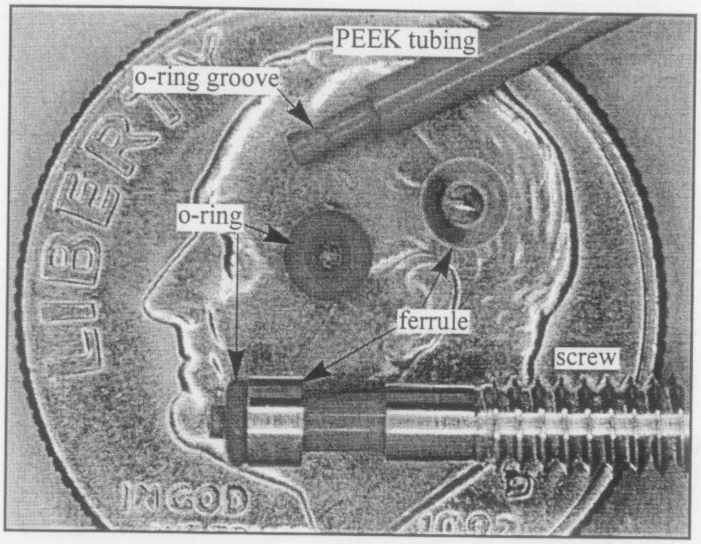


Figure 3. Section of a fluidic chip (bonded version of Fig. 1), showing compressible conductive polymer pillars which are inserted into holes for making contact to the electrodes.

3. MICROFLUIDIC INTERCONNECTS

While the technology for fabricating micron-scale fluidic structures is advancing rapidly, one of the main challenges in the field of microfluidic systems continues to be interfacing these devices to each other and to the outside, macroscopic world. In the process of demonstrating the microfabricated particle separator and sensor described in the previous section, we developed microfluidic interconnects which are easy to connect and disconnect, are reusable, do not require epoxy, have a low dead volume, are helium leak tight, can withstand hundreds of psi, and have a small footprint, allowing for multiple connections to be made in a very small area, thereby retaining the advantages of miniaturization. Standard PEEK high performance liquid chromatography (HPLC) tubing is used, with the tip formed to engage with either an o-ring or a molded gasket, which simultaneously provides a seal and mechanical retention strength.

The screw connector, pictured and sketched in cross-section in Fig. 4, has been used extensively to inject samples into the microfabricated particle impedance sensor. Figure 4 shows the PEEK tubing with its end machined to accept a ferrule and o-ring, also shown. A chamfer is machined at the tip of the tubing, allowing for easy engagement with and insertion into the port in the fluidic chip. The connection is made by inserting the tubing through the hollow screw which is then tightened by hand. When the screw is advanced, the o-ring is compressed into the o-ring groove and the tubing is pushed into the chip's fluidic



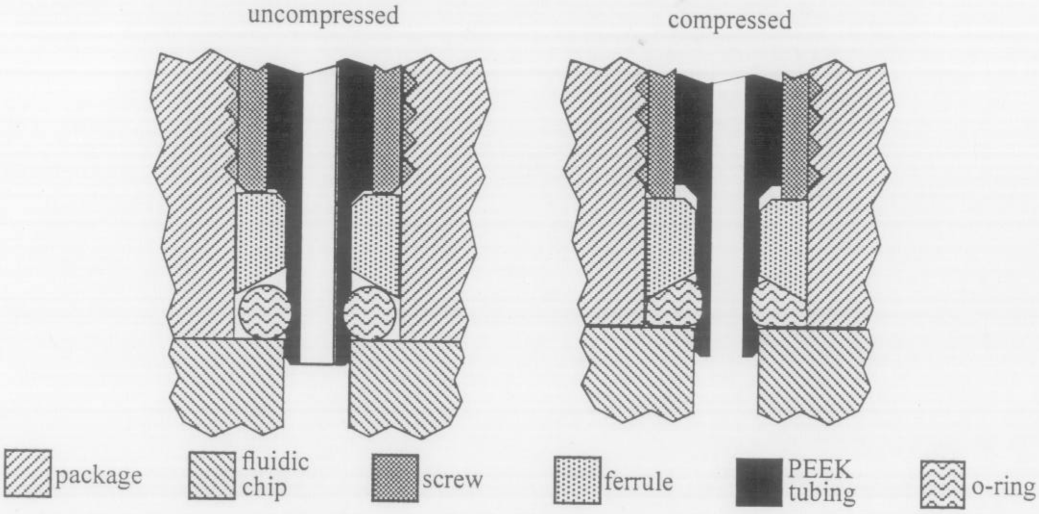


Figure 4. Screw connector. The connection is made by inserting the tubing through a hollow screw, which is then finger-tightened, compressing the o-ring and forming a helium leak-proof seal. By loosening the screw approximately 1/2 turn, the tubing can be removed, and later reinserted. The sketch shows a cross-section of the screw connector, before and after tightening the screw.

port, forming a seal between the chip and the tubing, and providing mechanical retention strength. The tubing can be removed by loosening the screw 1/2 turn, leaving the o-ring and ferrule trapped within the package, in place for reconnection.

In another design, shown in Fig. 5, the connection is established by plugging the tubing into a cartridge which is inserted into a counter-sunk hole in the package. The footprint of this connector is determined by the cartridge diameter (3.6 mm). Inserting the tubing pushes the cartridge against the fluidic chip, and the top o-ring locks onto the tubing while the bottom o-ring forms the seal. The tubing can be disengaged by pulling on it with sufficient force. In designing this type of connector, there is a trade-off between maximum sustainable pressure and degradation of the o-rings when the tubing is repeatedly disconnected. This interconnect can be used in the tip-insertion mode as shown, or in a butted configuration with the end of the tubing pressed directly against the fluidic chip, allowing for connections to a wide variety of microfluidic devices. Another version of the plug-in type connector, shown in Fig. 6, uses a custom polyurethane ring, molded at LLNL, in place of the o-ring cartridge. The molded ring fits inside a modified plastic set-screw which inserts into a tapped hole in the package. The tubing is placed through the screw, which provides a local preload at the connection site, increasing the maximum allowable pressure.

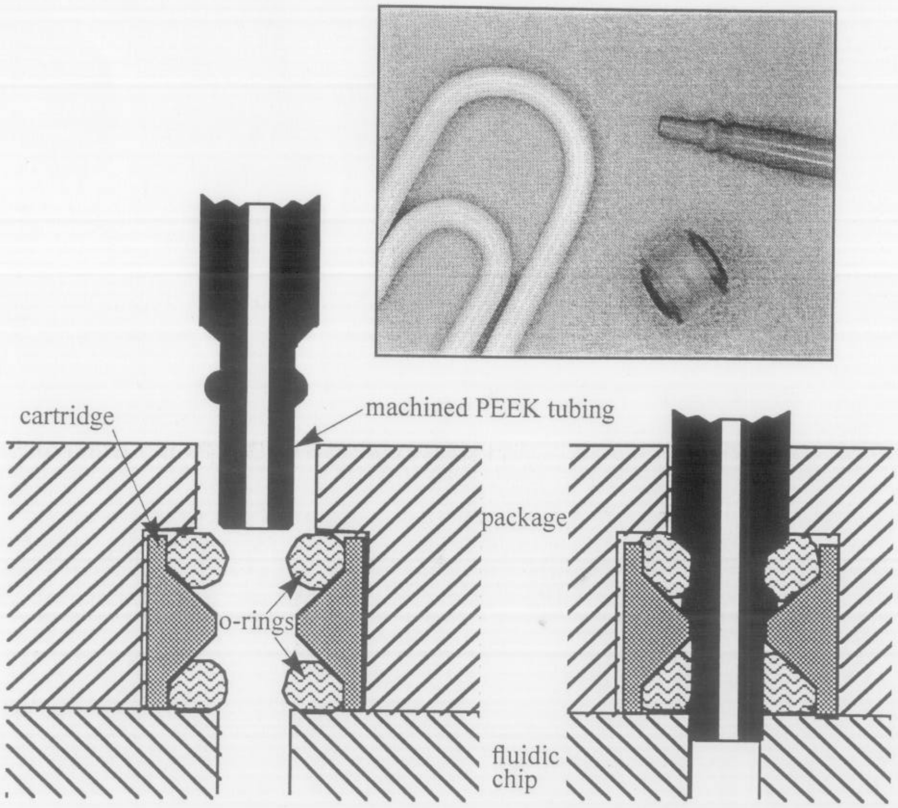


Figure 5. Snap-connector, showing the machined tip of standard HPLC tubing and the o-ring cartridge next to a paper clip. The cartridge is dropped into a counter-sunk hole in the packaging, and the footprint is determined by the cartridge diameter (3.6 mm). This interconnect can be used in a tip-insertion or butted configuration, allowing for connections to virtually any microfluidic device. The illustration shows a cross-section of the snap connector, before and after inserting the tubing.

Alternatively, the set-screw can be eliminated by dropping the molded ring directly into a counter-sunk hole in the packaging, resulting in a 2.6 mm footprint.

Helium leak testing was performed on the different interconnect designs by connecting to a dead-end fluidic port, attaching the opposite end of the 500 μm ID, 1.5 mm OD PEEK tubing to a helium leak detector, and releasing helium near the connector. All designs were found to be helium leak tight (see Table 1). Maximum pressure testing was performed by pressurizing the connectors with nitrogen gas, with the results also shown in Table 1. The screw connector did not fail when subjected to 1000 psi, the double o-ring snap connector leaked at 275 psi after the tubing was disconnected multiple times, and the molded ring snap connector tubing popped out of the fitting at 500 psi. In addition to leakage and pressure rating, dead volume, or space within the fluid pathway which is not cleanly swept by the flow, can be an important design concern for fluidic systems, primarily for applications in which carry-over from sample to sample cannot be tolerated. For the connectors presented here in which the tip inserts into the microfluidic chip, the dead volume is given by the gap between the inserted portion of the tube. This tolerance can be made small, but there is a trade-off between dead volume and ease of alignment. For applications in which dead volume is a critical concern, the butted connector configuration is a zero dead volume design.

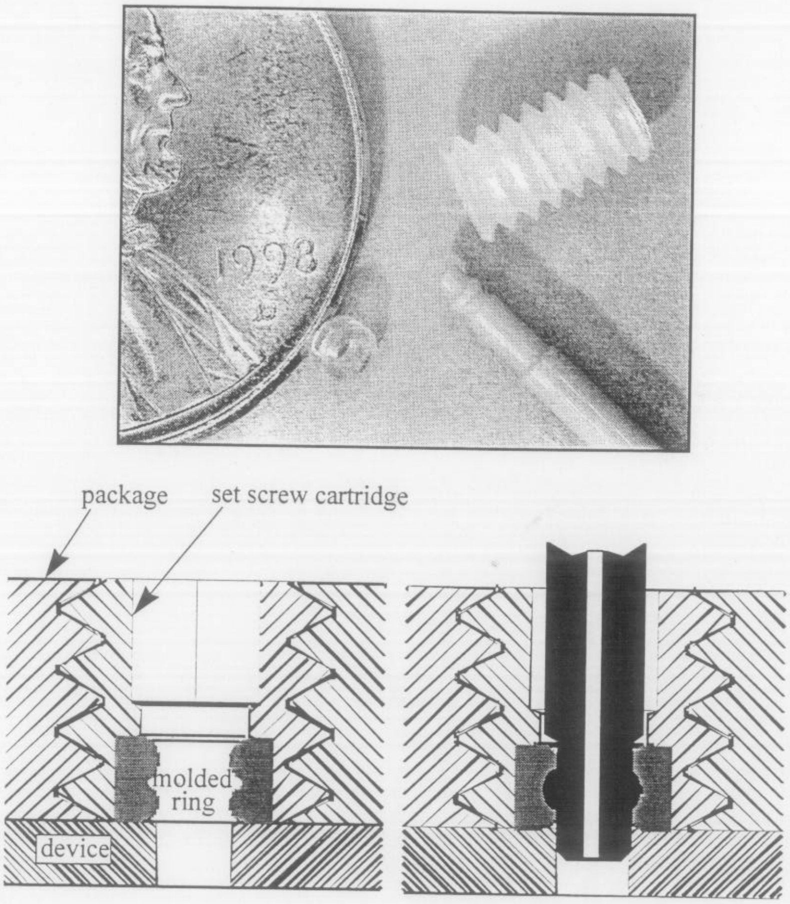


Figure 6. Second generation snap-connector, which incorporates a polyurethane molded ring and a modified set-screw. This connector applies local preload at the device's fluidic port and can be used in a butted or tip-insertion configuration. Alternatively, the molded ring can be dropped into a counter-sunk hole in the packaging, resulting in a 2.6 mm footprint. The illustration shows a cross-section of the second generation snap connector, before and after inserting the tubing

Table 1: Helium leak test and maximum pressure results for three connector designs.

Connector	Helium Leak Tight	Maximum Pressure
Screw Connector	Yes	Did not fail up to 1000 psi
Double O-Ring Snap Connector	Yes	Leaked at 275 psi after multiple disconnections
Molded Ring Snap Connector	Yes	Popped out at 500 psi

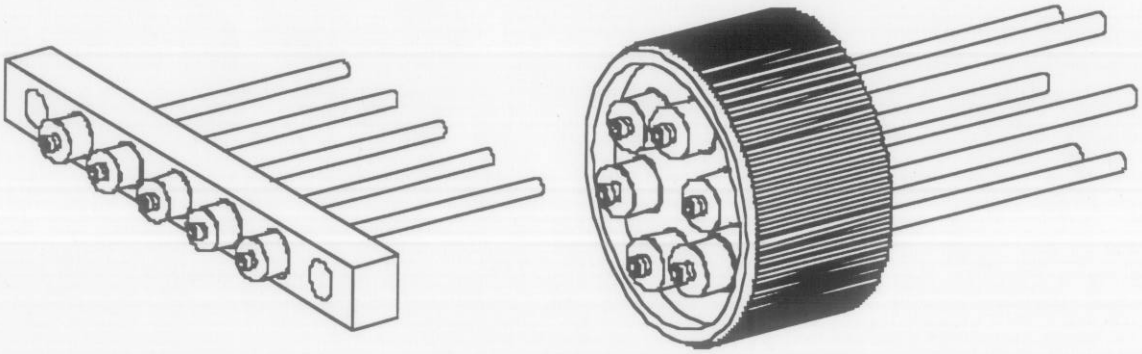


Figure 7. Linear and bundle microfluidic connector array concepts for enabling quick alignment and connection to multiple fluidic ports.

For microfluidic systems in which multiple fluidic connections are required, the connectors described above could be grouped in linear or bundle arrays, as depicted in Fig. 7. Analogous to electrical ribbon cables or military-type cable connectors, these arrays could be keyed and would allow for quick hook-ups during assembly or fluidic chip replacement.

4. CONCLUSIONS

A packaging and interconnection scheme for microfluidic systems was presented. The slide-together compression package is adaptable to a wide variety of microfluidic devices and allows for easy replacement of the fluidic chip. No tools, epoxy, wire bonds, or solder are required for assembly. The fluidic interconnects use standard PEEK tubing with the tip machined to accept either an o-ring or custom molded ring which makes the seal and provides mechanical retention strength. Three connector designs were presented, all of which were found to be helium leak tight and could withstand hundreds of psi.

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